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Advances in Study on Water Resources Carrying Capacity in China

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Abstract

The article systematically reviews the history of water resource carrying capacity and shows that water resource carrying capacity through three exhibition stages: initial, prosperity and development. The initial stage of the study is concentrated on environmental vulnerability arid area of northwest, and put forward the concept of water resource carrying capacity. it focus on the research of the theory, quantitative research is only initial. In this phase, the writer mainly uses two methods, which are trend in conventional and fuzzy comprehensive evaluation, to study. The prosperous phase of the study extends to urban areas, drainage basin, etc. In this stage, the research mainly probes into water resource carrying capacity from characteristic, connotation and the index system, which are using a variety of new mathematical models, in order to let the study gradually transmute into quantitative-rization. The expansion phase of the study refers to groundwater resources carrying capacity, the areas of Karst and irrigation .In this stage, theory study has been especially mature, there are the artificial neural network mode and projection trace appraises model besides the first two stages methods in quantitative-rization evaluation. In the future, the study of water resources bearing capacity will be combined with water resource optional distribution and ecological water requirement enhance study representative area, simultaneously, paying more attention to the issue of recycling Reclaimed Water; During the study, quantitative analysis should be combined with advanced means such as remote sensing, etc. which can realize the development of study from static to dynamics.

Keywords: water resources bearing capacity Stage division the tendency of research Research content Research methods Research areas

With the constant development of economy and technique, the problem of water resources has became gradually serious, people are beginning to study water resources bearing capacity, it is very important of correctly understanding and forecasting water resources bearing capacity. Now there are not many the single research results of water resources bearing capacity around world，and most of them are thinked as the sustainable development theory (Yuan, 2007), there are many studies about water resources in China but its starting is late.The author ranges it over three stages after reading a large number of documents: the years 1985—1994 are the initial stage ; the years 1995---2000 are the prosperous stage ; After the year 2000 is the expansion stage.

1. Initial stage (1985—1994), the research of water resources bearing capacity in XinJiang opens the research of water resources bearing capacity

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The earliest concept of water resources bearing capacity was originated from a word in《Ecology》 "bearing capacity"， and is a part of natural resources . but the earliest concept of bearing capacity was originated from the narrative about "the limited food to the support ability of population growth" in "Population theory" of Malthus(Zuo et al,2005), after this was gradually applied to Ground 、Ecology、Environment etc, The research of Land bearing capacity was more mature . United Nations Educational，Scientific，and Cultural Organization (UNESCO) putted forward the concept of resources bearing capacity in the 1980s : The resources bearing capacity of a country or area is a capacity that this country or area can sustained support population size, in the foreseeable period, Using these conditions of local energy and natural resources、intelligence、technique etc, and basing on conditions of material life level of ensuring compliance with social cultural norms (Duan et al,2010).

The earliest research of water resources bearing capacity of our country in 1985, Xinjiang water resource soft science research group firstly carried out the research, which is the water resources bearing capacity and development strategy of Xin jiang(Water Resources and Hydropower Engineering,1989). After this, our scholars were starting to the research work of water resources bearing capacity. Cai An-le(Cal,1994)discussed the water resources bearing capacity from the balance of supply and demand of water resources, relating different concepts of water resources bearing capacity for the change of the relation of supply and demand, and putting forward problems that should be paid attention when research Xinjiang water resources bearing capacity ,which should combine the feature of economic development and ecological environment etc: Yang Chuan-de(Yang,1990) analysed the current situation of Aibi Lake drainage basin from two aspects of surface water and underground water, selecting five basic parameters to calculate water resources bearing capacity of the perspective (2050),combining the natural conditions of research areas; Chen He-sheng (Chen,1988) referred to the basic criterion of calculating water resources bearing capacity and should consider the main factors; Shi Ya-feng (Shi et al,1992)applied trend in conventional to carefully study water resources bearing capacity of Urumchi drainage basin; Xu You-peng (Xu,1993)selected six factors that are related with local geographical conditions、economic development、People's life etc and applied fuzzy comprehensive evaluation to overall comprehensively evaluate Xinjiang he tian drainage basin. Water environment bearing capacity has been researched since the early 1990s . Guo Huai-cheng (Guo,1994)pointed out the indicators should be concerned with the water and water pollution for the water environment bearing capacity of cities, water supply and sewage disposal investment costs that were related with population、economy to represent, selecting seven indicators, which can reflect water environment bearing capacity of Ben xi development area ,to calculate water environment bearing capacity of middle and long-term based on two different projects.

This stage of research focus on arid region of west, this region climate is dry, rainfall precipitation is little, and evaporation is large, so water resources is relatively poor , the main irrigation、life、production with water region all come from surface water and underground water, The lack of water resources hindered the development all aspects, it is of great importance to research limited water resources bearing capacity ,and can offer support for formulating water resources development and utilization of policy. This period mainly proposed the concept of bearing capacity of water resources and water environment, the index parameters are able to represent water resources bearing capacity aim at natural conditions of study area, adopting trend in conventional and fuzzy comprehensive evaluation to comprehensively evaluate and predict for current and future of the water resources bearing capacity from the angle of water resources quantization.

2. Prosperous stage (1995—2000), the research of water resources bearing capacity base on city and drainage basin have thrived

This stage of research on water resources bearing capacity rapidly developed and reached to prosperous stage , many "nine-five" critical projects and natural science fund projects all refer to this field(Zhou,2010) the scope of attention is gradually expand, and the research contents became plentiful.

2.1 The research of urban water resources bearing capacity

City is the water concentrative areas , with the development of economy and the increasing pace of urbanization, water demand of urban development gradually increase , meanwhile the problems of the unreasonable utilization and water pollution make urban water consumption very nervous , especially water-deficient city , how to develop and use of all urban water supply is very important , the research of water resources bearing capacity may well reflected city water conditions and quantitative research played an important role in the research of water resources bearing capacity of cities, System dynamics simulation predicted is a method ,which used more, it mainly based on urban geographic environment、the characteristics of water resources and the state of economic development to select bearing targets , through the method of system dynamics to predictive analysis for the middle and long-term of water resources bearing capacity in different projects , for example Wei Bin (Wei et al,1995)、

Wang Jian-hua(Wang et al,1999)、Guo Huai-cheng(Guo et al,1995) respectively study for water resources bearing capacity of Ben xi and Wulumuqi; Cui Feng-jun(Cui,1998)analyzed that how to use system dynamics to make forecasting research for middle and long-term of water environment bearing capacity of urban in different strategies; moreover Xue Xiao-jie(Xue et al,2000) built Multi-objective decision-making model of core analysis and constraint condition , with xi an for example to forecast the middle and long-term of water resources bearing capacity, putting forward the strategy how to enhance water resources bearing capacity.

2.2 The research of river water resources bearing capacity

As the important water supply, river is the focus of attention all the time, water resources situation is different in different districts of river, water volume little in the upper reaches, supply is less, therefore water is shortage; water volume large in the middle and lower reaches, supply is relatively sufficient, but these are the regions of the fast development of economy, water demand is big, it assume of supply task is very large. In the meantime the pollution problem is striking too, it is of great importance to research water resources bearing capacity in different districts of river. Ruan Ben-qing(Ruan et al,1998) was based on system engineering method, with the sustainable development of regional economy、water resources sustainable utilization as criterion, with maximum of water resources comprehensive utilization efficiency as aim , building analysis and calculation model of regional water resources moderate bearing capacity, which applied the research of water resources bearing capacity to the area along the Yellow River downstream, calculating water resources bearing capacity for three goals years ; Xu Zhong–ming(Xu,1999)detailed the framework of the water resources bearing capacity multi-objective scene analysis, making use of scene analysis model to intensive study water resources bearing capacity of the Heihe river basin, research shows that use dynamic modelling analysis could better reflect the nature of systems; Qu Yao-guang (Qu et al,2000)calculated water resources bearing capacity of the Heihe river basin middle region on the basis of the calculation method of available water resources of water resources development and utilization in the arid regions, and the socioeconomic development in continental river drainage basin and water demand forecasting. Zhu Hu-gen(Zhu et al,1997)discussed the vulnerability of water environment bearing capacity of Huai river basin from three aspects of the characters of natural geography、the influence of Yellow River occupied Huaihe in history and the effect of inappropriate human activities , analyzing the influence to the three aspects ability of discharge and savings of flood of drainage basin、 providing effective water resources and water natural purification.

In addition, water resources bearing capacity of the west area is still to be concerned, Li Li-juan(Li et al,2000)and Chen Bing(Chen et al,2000)all adopted System dynamics simulation model to forecast and analyze the middle and long-term of water resources bearing capacity of Qaidam basin, proposing three schemes of high, medium and low, comparing and analyzing a comprehensive solutions of coordinated development of economy and environment.

Theoretical research constantly strengthened in this period, which prompted the research of water resources bearing capacity more mature. Li Li-juan(Li et al,2000)putted forward evaluation indicators, considering that population is the most direct indicator to evaluate the bearing capacity, the amount of water resources、per capita ownership etc several aspects are the auxiliary indexes; Wang Jian-hua(Wang et al,1999)discussed the connotations, namely space-time connotation 、 economic connotation 、 sustained connotation; Li Ling-yue(Li et al,2000)discussed the biodiversity characteristics of dynamics、relative extreme、fuzziness and to be bearing of water resources bearing capacity, and the mainly influence factors of the water resources bearing capacity and the mainly research contents, which enabled to fully understand the water resources bearing capacity.

3. The expansion phase (after 2000), the research of water resources bearing capacity more thorough

With the constant development of economy, the contradiction between supply and demand of water resources are more and more serious, and all kinds of types of water resources into the development and utilization planning, so the research scope of water resources bearing capacity began to widen, which mainly aimed at Surface water and underground water, not only more thorough for the study in the previous two stages, but also extended to karsts region、underground water、irrigated area etc.

3.1 The research of water resources bearing capacity in type area

3.1.1 The research of water resources bearing capacity in Karst region

In recent years, Water resources bearing capacity of karsts region attracted greatly attention, Karsts landform is completely developmental in the tropical and subtropical regions, which has enough moisture, and groundwater is relatively rich, hydrothermal condition is poor in the north , Karsts landform is based on the ground growth primarily, used surface water is richer than underground water, but the general condition is fragile ecological environment, it is difficult of recover after the water resources was damaged, so the research of water resources

bearing capacity of Karst region has became the mainly research objects. Deng Huang(Deng et al,2004)discussed the influencing factors of water resources bearing capacity of karsts region, which are water resources condition、Karsts ecological environment factors etc , suggesting enhance the water resources bearing capacity of karsts region from four aspects; Yang Xiu-ying(Yang,2006) made use of the BP neural network model of artificial neural network model to evaluate low water resources bearing capacity of Guilin Located in karsts region, marking out the zones of water resources bearing capacity; Wang Zai-gao(Wang et al,2001)putted forward the principle about building evaluation system of water resources bearing capacity of karsts region, namely regional、scientificalness、completeness and maneuverability etc, selecting ten indicators that reflect the condition of supply and demand of karsts region basing on these principles to build theoretical model, research and analysis of the water resources bearing capacity of Qing Zhen Shi gui zhou province; He Zhong-hua(He et al,2005)analyzed the low water resources bearing capacity of karsts region from the aspect of theory, characteristic、connotation etc with Guiyang for example; Zhou Liang-guang(Zhou et al,2006)was based two aspects on the population of water resources bearing in karsts region and economic growth to calculate the relatively water resources bearing capacity in Guizhou province, respectively contrast with the water resources bearing capacity of nationwide and non- karsts region, reaching the conclusion that water resources volume is rich , due to the influence of the karsts development made the relative water resources bearing poor; Yuan Zi-yun(Yuan et al,2009)applied Vector cosine method and mean square deviation method to confirm the index weight, utilizing Multi-objective grey relation projection method to research the water resources bearing capacity of various regions in Guizhou province, and contrasted the sort of the water resources bearing capacity of various regions through the each decision-making projection values; Zhou Liang-guang(Zhou et al,2006)discussed the appliance of principal component analysis and entropy in the research of water resources bearing capacity of karsts region, selecting four principal component that influenced the dynamic change of the water resources bearing capacity of Guiyang, which is located in karsts region from fifteen indicators and applied thermal charge to Weighting for it, figured out the comprehensive scores of the water resources bearing capacity of Guiyang, consequently obtained the change of the water resources bearing capacity.

3.1.2 The research of water resources bearing capacity of irrigated area and other special areas

Our country is a big agriculture country, with the development of economy and technique, developing some big grain production bases, for ensuring grain; the water is indispensable to agricultural production and form the water type of irrigated area. The irrigated area has its characteristics, it needs comprehensive consider the influence factors of the water resources bearing capacity when analyze it. Bai Jing (Bai et al,2010)used the Set Pair Analysis and use fuzzy comprehensive evaluation method to check the authenticity with the large scale irrigation in north for example, the results show that the potential of Water resources bearing capacity is relatively small before 2010, but the potential of water resources bearing capacity has a certain scale and strengthened gradually with the improvement of the ecological environment in 2020. Duan Qing-chun(Duan et al,2005)studied the characteristics of water resources bearing capacity in irrigated area, considering all kinds of crop was bearing capacity、the process of supply and demand of crop to establish relative model, reached the extent of water resources bearing capacity of the irrigated area in the third Puqing south Henan province. Wang Rong-jing(Wang et al,2009)comprehensively considered each factor, selected many correlation factor, applied Multi-level fuzzy comprehensive evaluation model to research the groundwater resources bearing capacity of People Sheng Li Qu irrigation, which intuitively reflected the extent of the underground water resources bearing capacity of irrigated area.

In addition, Zhang Su-zhen(Zhang et al,2004)analyzed the water resources bearing capacity of Baiyang Lake from two aspects of supply capacity of the water resources and the water environmental capacity; Xu Yong-fei(Xu et al,2009)was based on Multi-objective evaluation method and water resources bearing membership to analyze the water resources bearing capacity in the future10 to 20 years.

3.2 The research of underground water resources bearing capacity

The distribution of the underground water is more complex than surface water, which is influence through many factors of terrain、landform、lithology and precipitation replenishment etc. now there exist two big problems of excessive exploitation and pollution, so it is important to exactly understand the underground water resources bearing capacity. Zhan Xin(Zhan et al,2001)selected eight relativity evaluation indicators ,which was based on fully consider the difference of the underground water resources bearing capacity in the different zones, and the different way of development and utilization. The indicators was divided into three types according to have larger capacity、the bearing capacity approach saturation and the development potential is small; Shi Lei(Shi et al,2007)putted forward the researchful thinking of the underground water resources sustainable bearing capacity; Zhang Qin(Zhang et al,2008)took the underground water resources bearing capacity and the drought hang together, made use of Fuzzy

comprehensive evaluation model and Hierarchical analysis method, adopted qualitative and quantitative methods to research the water resources bearing capacity of Dawen river drainage basin, which could monitoring and forecast the regional drought in time; Zhang Wen-guo(Zhang et al,2002)was based on the evaluation to research the underground water resources bearing capacity, selecting two types factors that reflected the underground water environment bearing capacity to constitute the Index system of the underground water environment bearing capacity, using System analysis model and The fuzzy optimization model to respectively calculate the water environment bearing capacity and obtained the similar conclusion, which explained it could reflect the actual condition. Quantification is the outstanding feature in the research of the underground water resources bearing capacity, the mainly research methods as follow table one.

Table 1 The Research Methods of Underground water Resources Bearing Capacity

Researcher	Research contents	Research method
WAN Xing et al (Wan,2006)	Comprehensive evaluation on regional groundwater resources carrying capacity （A case study in Guanzhong region）	Set Pair Analysis
WANG Shun-jiu et al (Wang,2004)	Groundwater resources carrying capacity in Guanzhong plain	Projection Pursuit Method
MEN Bao-hui et al (Men, 2003)	Evaluating on of Resources Carrying Capacity of Regional Groundwater	Matter Element Model
KUANGJian-chao et al (Kuang,2007)	The potential evaluating and the counter-Measure research on exploitation and uti-izing of groundwater in Daqing Area	Matter Element Model
ZHANG Xin et al (Zhang,2001)	Comprehensive evaluation on resources carrying capacity of regional groundwater （A case study in Guanzhong region）	Fuzzy Comprehensive Evaluation

3.3 The research of urban water resources bearing capacity extend to small and medium—size cities

In the previous stage has begun on the research of urban water resources bearing capacity, This period ,the research was deepened from different angles to evaluate water resources bearing capacity and consider the influence of the comprehensive factor. Xia Jun(Xia et al,2006)was based on water cycle to analyze the influence of urbanization for the multiplexed system of" social economy --- water resources--- ecological and environmental" to research urban water resources bearing capacity; Li Ming(Li et al,2009)discussed the water resources bearing capacity of Chongqing metropolis circle from the balance of supply and demand , thinking that the water resources bearing capacity will not affect the economic development in short time; Not only appeared the water crisis in big cities, some middle-sized and small cities accelerated the pace of development, increasing the water demand, so the water resources has became a big restrictive factors. Li Shu-qin et al(Li et al,2008)was based on sustainable development , structured the index system of the water resources bearing capacity of Linyi, to comprehensively evaluate the water resources bearing capacity of linyi by using Fuzzy comprehensive evaluation method and analytic hierarchy process.

3.4 The research contents are various

The component of the water resources bearing capacity mainly include that the support ability of the water resources volume、the water environmental bearing capacity and the defense capability of The regional damage by

water, their respective functions and contents are different ,and have their own unique current capacity and threshold, but the capacity is the same that sustains the sustainable development in Feng Shang-you works(Feng et al,2002).thus the research of the water environment bearing capacity is a important aspect, its research is mainly theoretical from concept、characteristic、influencing factor in this period[45--53], Yang Wei(Yang et al,2008)made the detailed exposition for the advantages and disadvantages of the methods of each quantitative evaluation.

Besides the pure research of the water resources bearing capacity for permeating other aspects, one important research is to combining the ecology、the sustainable development and the reasonable configuration of the water resources, these three aspects are equal importance, the reasonable configuration of the water resources and the theoretical research of bearing capacity are the specific embodiment and the specific application of the sustainable development theory in the field of water resources management, the reasonable configuration is the technical means of the theory of the sustainable development, the bearing capacity is the conclusion of the theory of the sustainable development, that is to say, the water resources management strategy is sustainable after making the research of the reasonable configuration and the bearing capacity, conversely, have to make the research of the reasonable configuration and the bearing capacity to reach the sustainable development of the water resources development(Li et al,2000).Su Zhi-yong(Su et al,2002)studied the ecological economy of the water resources bearing capacity of Heihe drainage basin; Min qin wen (Min et al,2003)studied the way of ecological system to the water resources safety in northwest region; Xia Jun(Xia et al,2002)and Zhu Yi-zhong(Zhu et al,2003)studied the water resources bearing capacity combining the ecological water requirement.

The research of the water resources bearing capacity has got some achievements to run to the present stage, many scholars have done a lot of theoretical work [62--79], which laid the foundation for further development of the water resources bearing capacity. The research scopes expanded gradually in this stage, from the research of western arid region original expands gradually to Urban、drainage basin、the typical area; from the research of the surface water resources bearing capacity to the groundwater resources bearing capacity; from the research of the single object original to the research that was related with ecology、economy、population etc, the study was more and more careful.

4.Research prospect in future

There are a lot of the researches about the water resources bearing capacity, but some problems still to be solved. There are mainly several aspects.

4.1 The content of water resources bearing capacity

The definition of the water resources bearing capacity was proposed from the start, but each scholar has their own understanding, and the study was continuous perfection, so for, there is not a recognized concept, its understanding and definition needs to follow the following facts(feng,2002):

First, it must to be placed the strategy of sustainable development framework to discuss and has no meaning that leaves or deviates the social sustainable development mode.

Second, taking it as a member of the ecological system, and the support ability of the water resources is comprehensively considered for regional population、resources、environment and coordinated development of economy

Third, distinguishing the different characteristic of the water resources and other resources, it is both the reproducible, running, non-concentrated resources and can be depleted, pollution, interests coexist and uncertainty resources

Fourth, water resources bearing capacity is influenced by the natural factors, but also many social influence and restriction, such as socioeconomic status、national policy (including water policy)、control level and Social coordinated growth mechanism etc.

Though the explanation of the definition is not unified, summarize emphasis on three aspects: one is the bearing capacity of the comprehensive elements（Feng et al, 2003）; the second is mainly for the bearing capacity of the population(Zhu et a, l2002 and Ruan et al, 1998); the third laid stress on the bearing capacity of the social and economic development(Zhang et al,2003 and Ma et al,2009). Some scholars reduced the definition to two aspects [10,68, 77]: one is the developping scale theory or the capacity theory of the water resources; the second is the capacity theory of support sustainable development of the water resources. Sun Fu-xing(Sun,2006)defined the broad and narrow sense of the water resources bearing capacity, No matter which angle defined it to correspond with the above four principles. The author think that it should be the comprehensive bearing capacity for many factors, and base on the reasonable configuration of water resources、sustainable development and to ensure good ecological environment, including all water resources bearing capacity, according to the characteristic of water resources

bearing capacity, it is defined as all water resources offered the maximum capacity, passed the reasonable configuration of water resources, fitted the principle of the sustainable development, and ensured the good development of ecological environment, for population, agriculture, industry and other industries.

4.2 Evaluation methodology

Quantitative methods played a important role for correct understanding and prediction of the water resources, summing up the three stages methods that mainly have Multi-objective evaluation、Set pair analysis、Projection pursuit、The matter-element model method、Fuzzy evaluation method、the system dynamics simulation method、the general trend and so on, these methods are not suggested to aim at specific object of study, while the water resources possess the characteristic of dynamic change, so cannot completely reflect the change of water resources bearing capacity. These are traditional mathematical model, the accuracy is not high, and positive improvement, strengthen combine with other methods, for the selection of indicators considered the factors that can reflect the practical conditions to make accuracy higher; In addition which develop from static analysis to dynamic simulating(Yuan et al,2007). The application of some new methods should be strengthened, such as remote sensing technology, which can get much more and more accurately information.

4.3 Research contents

The research contents are more and more careful, which is mainly research the surface water resources bearing capacity and most of that in arid regions, but the study of the bearing capacity should be strengthened in water supply rich of central and eastern China, despite the large quantity of water resources, the water quality is gradually descend, which influenced the bearing capacity. The research of the underground water resources is less due to its complexity, but it is very important, especially in some special regions, as Jinan is a famous Quancheng, the research of the underground water resources is indispensable. Furthermore, the research should specific to the county(Ma et al,2005)、the research of special purpose region(development zones); the research is only in torrid zone and subtropical zone, the karsts landform also develop in the wide regions of north, the hydrothermal condition is not better than the south districts, its development is not complete, but it influented the local water resources bearing capacity to a certain extent, and needed to further study; Not only the research on the quantity of bearing capacity, but also on the qualitative bearing capacity, the water resources bearing capacity can be comprehensively reflected. The exploration on the new saving water should be strengthened, as water-recovery problem; furthermore, the research of the defense capability of the regional damage by water is a important content as the research of bearing capacity, strengthened the defense capability of The regional damage by water and enhance water resources bearing capacity at the same time. Besides it still be related with other domanial research, realizing the socIometric sustainable development.

5. Conclusion

The article reviews the research of water resource bearing capacity, the researchful achievement and shortage were to make conclusion for the different periods, thinking that got the achievement as follows:

(1) The theoretical research of water resource bearing capacity is very perfect, the discussion deeped into concepts、characteristic、connotations、evaluation system、significance.

(2) The evaluation methodology is diversification, realizing the size of water resource bearing capacity from the quantity, to combine with the remote sensing technology

(3) The survey region is more and more wide, from the earth's surface to the underground, the region of the lack of water resource expand to the rich in water supply, at the same time pay attention to be related with ecological water requirement and optimal allocation of water resources.

Shortage as follows:

(1) The explanation of the definition is not unified, focuses on the different factors, so brought hinder for further studying.

(2) A lot of the quantitative methods, but take the traditional mathematics models as the principal thing, these models are different from reality, the principles of selecting indicators is not perfect and can not accurately reflect the size of water resources bearing capacity

The future studies need to several aspects of development as follows:

(1) Combine with the remote sensing technology; gaining the real time dynamic data, from static to dynamics, and being able to effectively real time understand the change of bearing capacity

(2) Further strengthen the incorporation with ecological water requirement and optimal allocation of water resources, pay attention to the bearing capacity that is based on the principle of sustainable development; and

explore new water supply sources, the research of water resources bearing capacity should be strengthened on some special regions, such as industrial estate、irrigated area、wetland and so on .

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